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Bed Microenvironment in Hospital Patient Rooms with Natural or Mechanical Ventilation

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SUMMARY
We studied how to provide patients in bed with thermally comfortable microenvironment in both naturally and mechanically ventilated hospital rooms for both winter and summer seasons. A climate chamber was used to resemble a hospital room and thermal manikin to simulate a patient lying in a bed. The manikin was dressed and covered by a quilt with its head resting on a pillow. The effect of local heating was studied at room air temperature of 10 and 16 ^{o}C and of local cooling at 28 and 35 ^{o}C. Electrical radiant heater, heated blanket, heated pillow, personalized ventilation (PV) and heated boots were used to provide local heating and PV, cooled mattress, ventilated bed and cooling fan to provide local cooling. The heating/cooling effect of the methods (when used alone or combined) was identified by comparing heat loss from manikin's body and equivalent temperature with these obtained at a reference temperature of 22 ^{o}C. The effect of air movement (0.2, 0.4 and 1 m/s) at the bed vicinity was also studied. Electrical radiant heater in combination with heated bed showed to be the most effective at 10 and 16 ^{o}C and the combined use of PV and cooled mattress or ventilated bed was the most effective at 28 and 35 ^{o}C. Air movement with elevated velocity, especially 1 m/s, decreased the local heating/cooling effect.

KEYWORDS
Thermal comfort, local heating, local cooling, hospital environment, ventilation

1 INTRODUCTION

High quality indoor environment is required in hospitals. Optimal thermal comfort is important for quick recovery and comfort of patients and for comfort and health of health care workers. At present systems and methods designed to provide a fully mixed and uniform thermal environment in hospital rooms are used in practice. However this approach cannot provide at the same time optimal thermal environment for both patients and medical staff due to differences in their activity level (much higher for the staff) and physiological state of the body. Indoor air quality in hospitals is also important. The risk of cross infection, including hospital acquired infectious, can be high in hospitals. The ventilation requirements are thus usually high in hospitals. For example, a ventilation rate of 12 air changes/hour and more are required in isolation wards. Therefore often velocity is high which can be a reason for complains of draught.

Hospitals are mostly ventilated by conditioned and cleaned outdoor air; in some cases recirculation is allowed. Mechanical systems are used to condition and transport large amount of outdoor air. This strategy leads to substantial energy consumption, use of large air handling units, imposes limitations on flexibility in use and re-arrangement of the available floor area, etc. Ventilation rate higher than 12 air changes per hour may be achieved when natural ventilation is used (WHO, 2009). This may lead to energy saving. In case of epidemics, corridors and other not well ventilated area in hospitals are used to accommodate the increased flux of patients; in this case natural ventilation is often used. However the use of natural ventilation may affect negatively the indoor thermal environment with outdoor air temperature being cold or warm.

The use of individually-controlled systems for providing thermal comfort locally at the bed of each patient may be a solution to achieve optimal thermal environment for both patients and medical staff. High indoor air quality and decreased risk of airborne cross-infection may be achieved at reduced energy consumption when the strategy of bed thermal microenvironment is combined with mechanical or natural ventilation. The objectives of this study were to identify the performance of different cooling and heating method for generating bed thermal microenvironment at wide range of room air temperature and elevated air movement.

2 METHOD

Experiments were carried out in a climate chamber with dimensions 4.7 × 5.9 × 2.5 m^3 (W × L × H) with controlled environment. Mean radiant temperature is equal to the air temperature and radiant asymmetry is less than 0.1 ^oC. Low velocity (< 0.07 m/s) and low vertical air temperature gradient (< 0.2 ^oC) is achieved by an upward “piston flow” ventilation. Systems for supply of clean and conditioned outdoor air as well as cold and hot water exist.

A bed (0.8 m × 2 m × 1 m) was placed in the middle of the chamber. The bed had a mattress of thickness 8 mm, covered with thin cotton sheet, a pillow and a quilt enveloped in light cotton bed lining (thermal insulation of 1.5 Clo). Thermal manikin was used to simulate a patient lying in the bed. The manikin closely resembles the complex body shape of an average Scandinavian woman of 1.7 m height. Its body consists of 23 body segments. The segments are separately controlled to maintain surface temperature equal to the skin temperature of a person in state of thermal comfort. The dry heat loss and surface temperature of each segment is measured. The manikin was calibrated prior to the experiments. The manikin was dressed in a typical hospital pajama consisting of top and trousers with a total isolation of 0.61 Clo.

A “wind” box with dimensions 2 m × 1 m × 0.8 m was used to generate airflow simulating natural ventilation through a window. Two fans, airflow strengthener and filter were installed in the box with perforated front wall to generate uniform airflow. Airflow with different velocity (up to 1.5 m/) was generated by regulating the fan speed. When used the box was placed with its long side in parallel with the left bed side at distance of 2 m and 0.4 m above the floor so that the middle of the box was aligned to the manikin.

Different methods for local heating or cooling were used to generate bed microenvironment (Figure 1). At room temperature lower than the comfortable winter temperature recommended in the standards (20 ^oC), i.e. simulated winter conditions, the following heating methods and equipment were used: *Electrical Radiant Heater* (ERH or RadH) working at low, middle and high power (670, 1350, 1940 W). The ERH was placed either on the side of the head or at the side of legs at different height (from 0.75 to 1.1 m above the level of the mattress) and angle; *Electric Blanket* (EB) divided into two parts: upper - for heating the torso and lower – for heating the legs. Each of these two parts could work on low, middle and high power modes independently. The used combinations of upper/lower parts were: OFF/Low (4.5 W), Low/OFF (4.5 W), Low/Low (9 W), Low/Middle (39 W), Middle/Middle (69 W). EB was placed bellow the manikin, between the mattress and the sheet; *Electric Pillow* (EP) providing heat of 94 W. At air temperatures above the comfortable temperature recommended in the standards (26 ^oC) the methods for local cooling were: *Personalized Ventilation* (PV) attached to the bed on the side of the head and supplying cool air (23–30) ^{o}C. An air supply device positioned 0.55–0.65 m height above the bed mattress directed personalized flow (6-8.5) L/s against manikin's face/chest area; *Water Cooled Mattress* (WM) with the bed dimensions was simulated by a plate with build in tubes with circulating water at temperature of 28 - 31 ^{o}C. The bed mattress was placed above the WM; *Bed Ventilation* (BVP) was simulated by a flexible pipe providing air (6 L/s) at temperature (27–30) ^{o}C bellow the quilt from the side of manikin's feet; *Electric fan* (EF) attached to the bed on the head or feet side at different heights (0.4 m - 1.2 m) above the mattress discharged airflow to cover manikin's face and large body area. The power used by the fan was 44 W. It could be used at three speed settings.

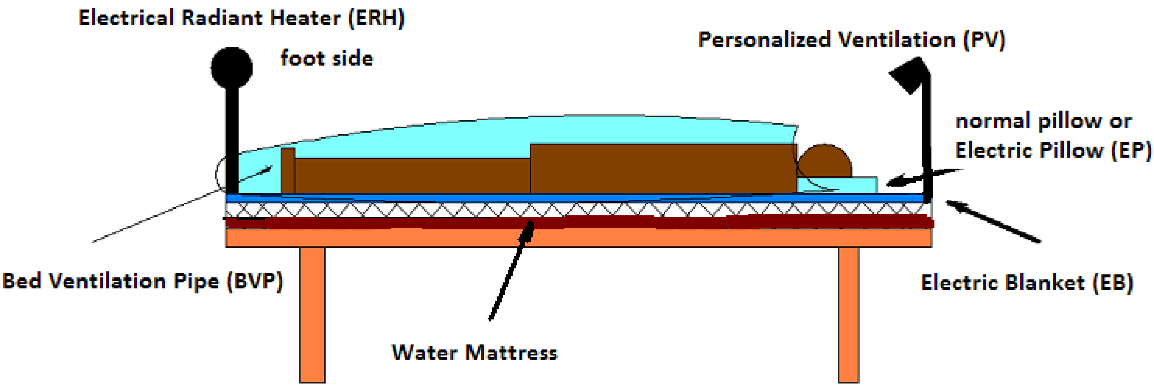

Figure 1. The methods used for local heating and cooling.

The velocity of the flow from the wind box was measured by a multichannel low velocity thermal anemometer (type HT400) with 7 omnidirectional velocity probes. The measurement accuracy is ± 0.03 m/s. The temperature in the bed, measured at several locations (temperature sensors type "Crafttemp") was collected by data-logger. The measurement accuracy was ± 0.2 °C. The personalized airflow rate was measured by a pressure difference sensor ("Micatrone") installed in the supply duct (accuracy 0.01 Pa ± 0.25% of the reading). The relative humidity was measured using a hygrometer (accuracy ± 3%).

The bed microenvironment was studied at room air temperature of 16 ^{o}C and 10 ^{o}C (winter case) and 28 ^{o}C and 35 ^{o}C (summer case) with the local heating/cooling methods used alone or in combinations. A reference experiment at room temperature of 22 ^{o}C was performed. The setting of room air temperature is based on the variation from the reference temperature by nearly every 6 degree, in order to simulate the winter and summer weather locally. The quilt was used for the reference case and the winter cases; for the summer case a light cotton sheet covering the manikin to the neck was used. Experiments with manikin's arms and hands covered and not covered were performed. More than 55 experiments were performed. The heat flux and surface temperature measured with the manikin were used to determine the equivalent temperature, t_{eq}, for each body segment and the whole body (ISO14505-1, 2004). The difference (Δt_{eq}) between the equivalent temperature (t_{eq22}) determined for the reference case (22 ^{o}C) and the equivalent temperature determined for studied conditions was used to assess the bed thermal micro environment. Δt_{eq} shows how many degrees cooler or warmer the bed microenvironment at the tested conditions is compared to the microenvironment obtained at the reference temperature of 23 ^{o}C.

The experimental procedure was: the chamber target temperature was set; the manikin, lying on its back and facing the ceiling was switched on; the used devices for local heating/cooling were switched on; manikin measurements, room air and bed temperature were measured after steady-state conditions were obtained in the chamber.

3 RESULTS

Large database was collected and analyzed. Only some of the results on improved bed microenvironment obtained with combination of not more than two methods are presented. As expected local heating/cooling was needed at the "winter" and the "summer" temperatures. For the winter conditions (10 ^{o}C or 16 ^{o}C) radiant heater (RadH) placed above manikin's head and combined with electric blanket led to substantial improvement (Figure 2). The results in the figure show that manikin's lower segments needed to be heated more while the upper segments were heated 2-3 °C above the reference case of 22 °C. Δt_{eq} close to 0 was obtained for the head and chest when the power of the RadH was decreased from 1350 W to 670 W (not shown). More heating power from the lower part of the electric blanket could help to decrease the heat loss from the lower body segments and to bring it to the reference case level. An increased air movement leads to increase the heat loss mainly from the body segments not covered, i.e. the top of the head (crown) and the face (Figure 3). The heat loss from the left face positioned against the air movement was slightly higher than that from the right face.

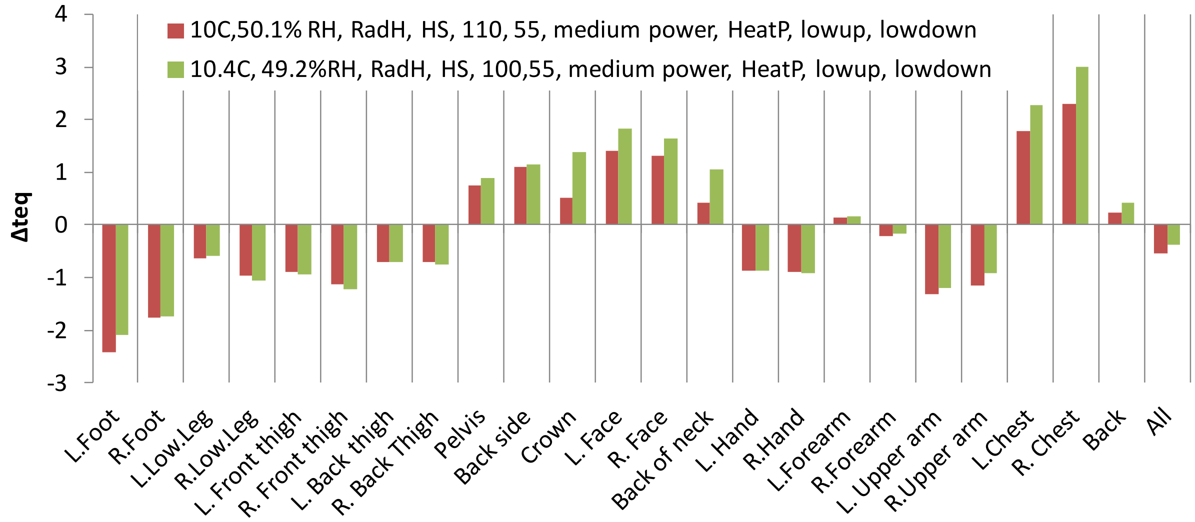

Figure 2. Room air temperature - 10 ^{o}C, relative humidity – 50%, air velocity – 0.05 m/s. Δt_{eq} determined with radiant heater (RadH) working at medium power (1350 W), positioned at the head side (HS) at 1.1 m (brown color) or 1.0 m (green color) and inclined 55° (downward toward the lying manikin) when combined with electrical blanket with upper and lower sections performing at low power.

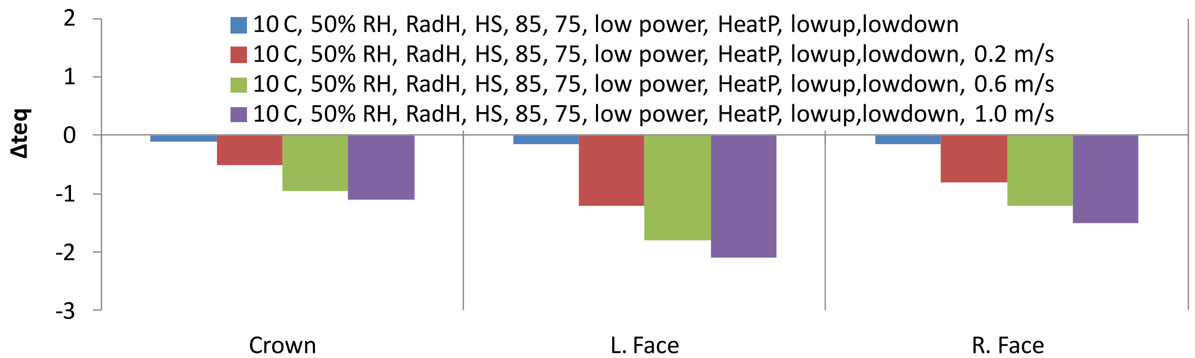

Figure 3. Room air temperature - 10 ^{o}C, relative humidity – 50%, air velocity – 0.05 m/s. Radiant heater (RadH) working at low power (670 W) positioned at the head side (HS),at height of 0.85 m, inclined 75° downward toward the lying manikin and electrical blanket bellow the manikin with upper and lower sections performing at low power. The impact of airflow velocity (0, 0.2, 0.6, 1.0 m/s) at the location of the manikin is shown.

In the summer conditions (28 ^{o}C and 35 ^{o}C) most challenging was to improve the bed microenvironment at 35 °C. At this temperature personal ventilation combined with bed ventilation or water cooled mattress was efficient (Figure 4). The air movement had negative impact on the exposed body segments. The warm air moved at high velocity diminished the cooling effect of the cold personalized air for the head (Figure 5).

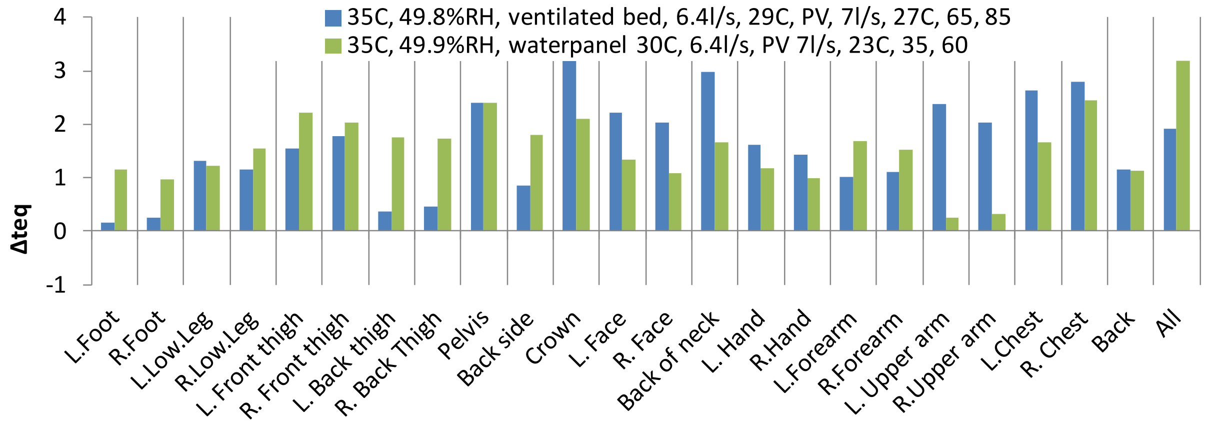

Figure 4. Room air temperature - 35 ^{o}C, relative humidity – 50%, air velocity – 0.05 m/s. Bed ventilation (airflow - 6.4 L/s, 29 ^{o}C), PV (airflow - 7 l/s, 27 ^{o}C) at height 0.65 m and flow discharge at 85° and cooled mattress (30 ^{o}C), PV (airflow - 7 l/s, 23 ^{o}C) at height 0.35 cm and flow discharge at 60°.

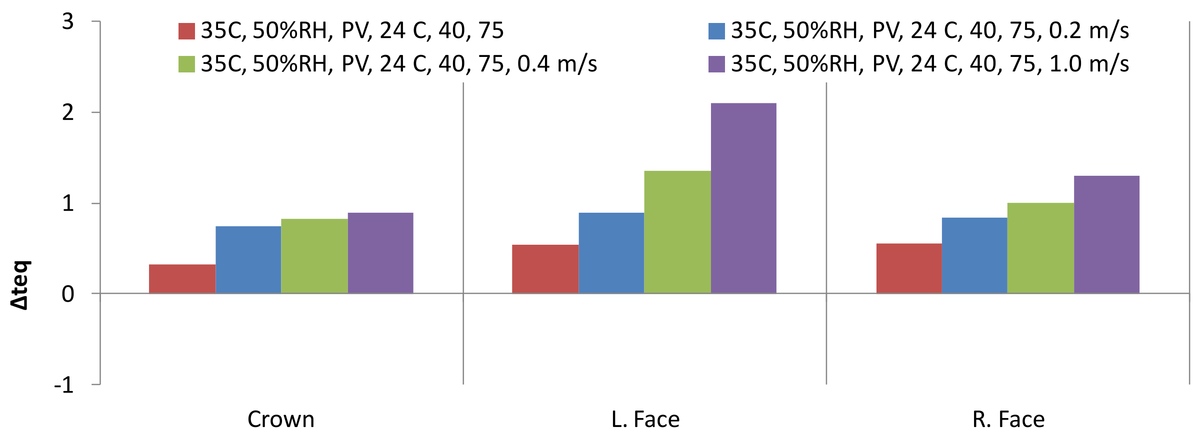

Figure 5. Room air temperature - 35 ^{o}C, relative humidity – 50%, air velocity – 0.05 m/s. PV (airflow - 7 l/s, 24 ^{o}C) at height 0.4 m and flow discharge at 75°. The impact of airflow with velocity of 0, 0.2, 0.6, 1.0 m/s at the location of the manikin is shown.

4 DISCUSSION

The results reveal that combinations of the tested methods for local heating/cooling can improve the bed microenvironment to the reference level when the room air temperature was several degrees (4-6 °C) bellow or above the temperature range (21-24 °C) recommended in the standards for patient rooms (ASHRAE Standard 170-2007). Large non-uniformity in the local heat loss from the body parts covered with bed clothing and those not covered may exist when the room temperature is too low and too high (e.g. 8 °C or more) than the comfortable temperature. This will lead to complains of local thermal discomfort from patients. The use of more than two methods for local heating/cooling is not feasible in practice due to difficulties in control and maintenance. At room temperature of 16 °C it was possible to decrease the heat loss from manikin's body segments to be close to that at the reference temperature by using only two local heating methods, namely radiant heating and electric blanket, while this was difficult at 10 °C. The use of natural ventilation at high ventilation rate will decrease the risk of cross-infection but will increase indoor air velocity. It will cause local cooling and will diminish the positive effect of the used local heating methods. In this case the recommended minimum room temperature will differ less than the comfortable temperatures. Despite of this, the use of individually controlled bed microenvironment together with natural ventilation can be recommended when the outdoor temperatures are not too cold. For example at outdoor temperature of 18-19 °C the thermal environment in patient rooms with natural ventilation providing relatively high ventilation rate (indoor velocity up to 0.4 m/s) may be comfortable for medical staff with high activity and for patients in bed with controlled microenvironment.

Personalized ventilation combined with bed ventilation or water cooled mattress improved the bed microenvironment at temperature up to 35 °C. The improvement was due to the dry heat loss from the manikin. Further improvement of patients’ thermal comfort may be expected because evaporative heat loss will also occur. At outdoor temperature of 34 °C and above the use of natural ventilation providing high air change rates in hospital patient rooms, i.e. improved air quality and decreased risk of airborne cross-infection, in combination with personalized ventilation for cooling may not be the most efficient because the naturally generated movement of warm air will diminish the cooling by the personalized ventilation. The other methods providing cooling in the bed, i.e. bed ventilation, cool mattresses, etc., will be less influenced by the naturally generated air movement. In dry climates these cooling methods combined with natural ventilation that will increase the evaporative cooling may be efficient. Within the context of human response to the non-uniform thermal environment, bed microenvironment with personal control is recommended.

The energy consumption aspect is another aspect to be considered. The electrical power used by some of the devices, e.g. local radiant heating, was high. There is need to develop efficient heating/cooling methods for the body parts exposed to the air.

5 CONCLUSIONS

The local heating/cooling methods improve the bed microenvironment and will provide patients in hospitals with thermal comfort at indoor air temperature with wider range than that recommended in the standards. The heating/cooling effect of the tested devices diminishes at elevated room air velocity as a result of high ventilation rates provided by mechanical or natural ventilation. Use of individually controlled bed microenvironment together with advanced air distribution methods for local ventilation and source control is recommended.

ACKNOWLEDGEMENT

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